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Research Article

How many marine aliens in Europe?

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Abstract

In the framework of the European Alien Species Information Network (EASIN; http://easin.jrc.ec.europa.eu/), an inventory of marine alien species in Europe was created by critically reviewing existing information in 34 global, European, regional and national databases. In total, 1369 marine alien species have been reported in the European seas (including 110 cryptogenic and 139 questionable species); this is a substantial increase from the 737 species previously reported in 2009 based on the DAISIE (Delivering Alien Invasive Species Inventories for Europe; http://www.europe-aliens.org) dataset. Most of the reported species were invertebrates (63.3%), followed by chromists (13.7%), vertebrates (11.6%), and plants (10.1%). Mollusca is the most numerous phylum, followed by Arthropoda, Chordata, and Annelida. The countries with the highest reported numbers of marine alien species were Israel, Turkey, Italy, France, Egypt and Greece. A reporting bias is evident as efforts for monitoring and reporting alien species vary among countries.

Key words: biological invasions; EASIN; European Seas; information system; non-indigenous species

Introduction

A stepping stone for the assessment of biological invasions is the collection of basic information on the occurrence and spatial distribution of alien species, pathways of introduction, spread rates, life histories, biological and ecological traits. This information is necessary to model the demographic rates of alien populations in relation to environmental characteristics, and assess their interaction with native biota and their large-scale impact. It is also a prerequisite for the efficient prevention, early detection, rapid response, and management of biological invasions (Lee et al. 2008; Simpson et al. 2009; Hulme and Weser 2011). In recognition of that need, a large number of networks for the reporting of alien species occurrences and online databases have recently appeared, providing information on alien species on a national, regional, or global scale (Simpson et al. 2009; Katsanevakis et al. 2012).

Online databases have provided the basic information for various assessments of alien invasions in Europe, evaluating their impacts, and assessing the role of ecological and socioeconomic factors. In particular, the DAISIE (Delivering Alien Invasive Species Inventories for Europe; http://www.europe-aliens.org) inventory offered the most comprehensive dataset on a European scale and provided an excellent opportunity to perform analyses of the invasion patterns of a wide range of taxa in terrestrial and aquatic environments (e.g. Chiron et al. 2009; Vilà et al. 2010; Pyšek et al. 2010). However, a recent comparative analysis of 43 online databases revealed that even DAISIE did not include >20% of the marine species reported in all databases. When offline resources were considered, the total reported number of marine alien species in Europe substantially increased (Gatto et al. 2012). In addition, there are large variations among databases in their taxonomical, environmental, and geographical scopes; there is variation in efforts to update the databases; and there are inconsistencies on the definition of 'alien' or 'invasive' species, which is often a cause of debate (e.g., Zenetos 2010). Many

databases did not explicitly define which species were considered alien or invasive alien, and those that did used a range of different definitions and criteria (Hulme and Weser 2011; Gatto et al. 2012).

One approach to improve the quality of information on alien species, increase its accessibility, and ultimately support a cost-efficient European invasive alien species policy is to create a network of online interoperable web services, through which all information scattered in various databases can be accessed (Vandekerkhove and Cardoso 2011). Under this approach, local information would be collected and assessed through efficient local networks of experts and citizens, while at the same time an integrated accurate view on a European scale would be feasible. The European Commission's Joint Research Center (JRC) has put efforts towards building such a network, specifically through the European Alien Species Information Network (EASIN; http://easin.jrc.ec.europa.eu/; Katsanevakis et al. 2012). EASIN allows extraction of alien species information from online information systems for all species included in the 'EASIN catalogue'. This catalogue was based on an inventory of reported alien species in Europe that was produced by reviewing and standardizing existing information from 43 online databases and selected offline sources (databases not available online and published literature). Herein, we present an overview of the marine part of the EASIN catalogue and provide an estimate of the total number of reported marine alien species in Europe, their taxonomic identity, and their distribution by country.

Methods

Among the 43 databases used for the compilation of the EASIN catalogue, only 34 included the marine environment: 5 with global coverage, 1 with European coverage, 6 with regional coverage, 19 with national coverage, and 3 with sub-national coverage (first two columns of Table 1). Some of these databases specifically targeted alien species, while some others served a more general purpose of biodiversity monitoring (third column of Table 1). Among general-purpose databases targeting biodiversity, only those in which it was possible to retrieve specific information about the alien/native status of each species by country were considered (e.g. GBIF was not included in the analysis for not satisfying this criterion). Alien species names were retrieved from these online resources for all European countries having a marine coastline (as listed in http://europa.eu/about-eu/countries/index_en.htm). In addition, we included alien marine species reported from all countries surrounding the entire Mediterranean Sea.

From each of the 34 databases, all names of species listed as 'alien', 'introduced', 'casual alien', 'invasive' or 'cryptogenic' (i.e. species with no definite evidence of their native or introduced status) were extracted. 'Questionable' species, i.e. species with insufficient information or new entries not verified by experts or species with unresolved taxonomic status, also were included. Species listed as 'potential aliens' (watch lists), 'reintroduced', 'excluded' or 'extinct' were excluded. Marine species with type locality within the same regional sea (e.g., NE Atlantic species reported as aliens in the North Sea) were excluded. Vagrant species that have entered the Mediterranean via Gibraltar (mostly tropical Atlantic fish and decapods) or Mediterranean planktonic species that entered the Black Sea via the Dardanelles Straits were excluded.

The extracted species names were revised in a multi-step process to harmonize notations across databases and identify duplicate taxon entries. To facilitate the process, species names were split over multiple columns using the Excel "text to column" function. Names with a taxon rank higher than species level were deleted; abbreviations were conformed with international nomenclature (International Code of Botanical Nomenclature, the International Code of Zoological Nomenclature and the International Code of Nomenclature of Bacteria) (e.g., ssp., sub., and subspecies were replaced by subsp.); taxon rank specifications (agg., cf., s.l., s.str., and hyb.) and author's names were removed from the species name and added to specific extra columns; special characters were substituted, according to international nomenclature codes; supplementary acronyms, numbers, and text were deleted; taxon names with multiple taxon ranks (e.g., subsp. and var.) were corrected through hierarchical cross checking in the World Register of Marine Species (WoRMS), the Integrated Taxonomic Information System (ITIS), the Catalogue of Life (CoL) and the Global Biodiversity Information Facility (GBIF). Duplicate names were then removed using Excel's "Remove Duplicate" function. By this procedure, subspecies, variants and hybrids were kept as separate records.

Table 1. The 34 databases reporting marine alien species in Europe that were used in this analysis, and their coverage, specificity, and URL.

Database	Coverage	Specific for alien species	Website
BALTIC SEA	Regional - Baltic sea	Yes	http://www.corpi.ku.lt/
BE	National - Belgium	Yes	http://ias.biodiversity.be/ias/
BE-MAR	National - Belgium (marine)	Yes	http://www.vliz.be/
BY-AQ	National - Belarus (aquatic)	Yes	http://aliensinbelarus.com/
CAN. ISL.	Sub-national - Canary Island	Yes	http://www.interreg-bionatura.com/
CASP-SEA	Regional - Caspian sea (aquatic)	No	http://www.caspianenvironment.org/biodb/
CIESM	Regional - Mediterranean (marine)	Yes	http://www.ciesm.org/
DAISIE	Europe	Yes	http://www.europe-aliens.org/
DE-AQ	National - Germany (aquatic)	Yes	http://www.aquatic-aliens.de/
DK	National - Denmark	Yes	http://www.naturstyrelsen.dk/
EE	National - Estonia	Yes	http://eelis.ic.envir.ee/
EE-MAR	National - Estonia (marine)	Yes	http://www.sea.ee/
EL-AQ	National - Greece (aquatic)	Yes	https://services.ath.hcmr.gr/
ES	National - Spain	Yes	http://invasiber.org/
FAO-DIAS	Global (fisheries-related)	Yes	http://www.fao.org/fishery/introsp/search/en
FISHBASE	Global (only fish)	No	http://www.fishbase.org/
GISD	Global	Yes	http://www.issg.org/
GM	Global	Yes	http://conserveonline.org/
IE	National - Ireland	Yes	http://invasives.biodiversityireland.ie/
ISC	Global	Yes	http://www.cabi.org/isc/
LAT-FISHES	National - Latvia (only fish)	No	http://latvijas.daba.lv/
LT	National - Lithuania	Yes	http://www.ku.lt/
MAMIAS	Regional - Mediterranean	Yes	http://www.mamias.org
NL	National - Netherlands	No	http://www.nederlandsesoorten.nl/
NO	National - Norway	Yes	http://www.artsdatabanken.no/
NOBANIS	Regional - Northern and Central Europe	Yes	http://www.nobanis.org/
PO	National - Poland	Yes	http://www.iop.krakow.pl/ias/Baza.aspx
REABIC	Regional - Euro-Asian	Yes	http://www.reabic.net/
RU-ANIMALS	National - Russia (only animals)	Yes	http://www.biodat.ru/
SE-MAR	National - Sweden (marine)	Yes	http://www.frammandearter.se/
UK	National - UK	Yes	https://secure.fera.defra.gov.uk/nonnativespecies/
UK/E	Sub-national - England	Yes	http://www.brc.ac.uk/resources.htm
UK/N	Sub-national - north. Ireland	Yes	http://www.habitas.org.uk/
UK-MAR	National - UK (marine)	Yes	http://www.jncc.gov.uk/page-2597

Potential spelling errors (max. 3 characters) were identified semi-automatically using the Excel add-in 'Fuzzy duplicate finder' (AbleBits, Homel, Belarus; www.ablebits.com). Pairs of names obtained this way (potential duplicates) were cross-checked in a hierarchical way with WoRMS, ITIS, CoL, Encyclopedia of Life (EoL), and GBIF, to assess which entry was valid. If the questioned names were both valid, they were both kept as different taxa, otherwise the invalid name was replaced by the valid one. As a last step, synonyms present in the list were identified through a cross-check with ITIS, WoRMS, and CoL, and a further correction of invalid names and removal of duplicate records was done. Synonyms were checked in WoRMS using the "match taxa" tool provided in the WoRMS website, in ITIS by extracting them from the downloadable version of the databases, and manually in CoL.

Taxonomic classification (Kingdom, Phylum, Class, Order and Family) of each alien taxon was retrieved in a hierarchical way from WoRMS, ITIS, CoL and GBIF. Taxonomy of yet unresolved names was completed by following the source database or through literature search. 'High-impact' species were defined based on the lists of DAISIE, GISD, SEBI-2010, CABI, NOBANIS, and the review by Zenetos et al. (2010).

Results and discussion

To date, 1369 marine alien species have been reported in the European seas (including 110 cryptogenic and 139 questionable species). Of these, 382 species are casual records, i.e. they have been recorded only once and their establishment success is yet uncertain. All the species names and their taxonomy may be

retrieved from EASIN (http://easin.jrc.ec.europa.eu/use-easin/Combined-Criteria-Search; version 2.1 of the EASIN catalogue as of September 2012).

The previous published review of marine alien species in Europe was conducted in 2009 in the DAISIE framework (Galil et al. 2009) and it listed 737 marine alien species in the European seas. The larger number of marine aliens species reported herein is due to various reasons. (1) The marine part of DAISIE appears to have been insufficiently updated after the end of the project in 2006. For example among the 185 species reported in the Mediterranean Sea after 2006 (based on MAMIAS records), only 12 (i.e., 6.5%) were included in the DAISIE database (based on data retrieved in August 2011; Gatto et al., unpublished data). (2) There have been many new alien introductions since the Galil et al. (2009) review. For the Mediterranean alone, the rate of new introductions has been estimated at one every 1.5 weeks (Zenetos 2010) and the total number of reported marine aliens has approached 1000 species (Zenetos et al. 2010). (3) Some taxonomic groups are not well represented in DAISIE, e.g. 68 Foraminifera are reported herein but none were included in DAISIE; from the 164 Annelida and 66 Cnidaria reported herein, DAISIE included only 64 (39%) and 37 (55%) respectively. (4) Marine alien species from 41 countries have been included herein, whilst DAISIE was based on data from 35 countries. For example, the Black Sea countries were not included in the Galil et al. (2009) review, and 84 alien species have been exclusively reported from the Black Sea. (5) The Galil et al. (2009) review included only multicellular species, while we have included 78 unicellular algae.

The largest group of reported marine alien species of European seas were invertebrates (63.3%), followed by chromists (13.7%), vertebrates (11.6%), and plants (10.1%). Mollusca was the most numerous phylum, followed by Arthropoda, Chordata (mainly fish), and Annelida (Figure 1). The same 4 Phyla were the most numerous in terms of high-impact species but with Chordata being first, followed by Arthropoda, Mollusca, and Annelida (Figure 1). The true marine alien distribution by taxonomic group might deviate a bit from the reported one, especially for less studied taxonomic groups that might be underrepresented in existing monitoring and reporting schemes.

Reported per country numbers of alien species varied from 5 (Georgia and Monaco) to 432 in Israel and 428 in Turkey. High numbers of marine aliens have also been reported in Italy (277), France (266), Egypt (238), Greece (222), Lebanon (214), and Spain (201) (Figure 2). The per country distribution of alien species is affected by several factors: (1) the varying impact of specific pathways of introduction, e.g. Lessepsian species (introduced through the Suez Canal) mostly affect the countries around the Levantine, which partly explains the high number of species reported in Israel despite its relatively small coastline; (2) the number of different ecoregions (i.e. biogeographic units, *sensu* Spalding et al. 2007) within a country's marine territory, i.e. countries that include more than one ecoregions would be susceptible to a larger pool of alien invaders; e.g. Turkey's waters span three ecoregions (Aegean Sea, Levantine Sea, and the Black Sea, according to the classification by Spalding et al. 2007), which partly justifies the large number of marine alien species reported in Turkey; (3) the length of the coastline, e.g., Bosnia and Herzegovina with only 26 km of coastline is expected to have a lower number of alien species compared to neighbouring countries having much longer coastlines; and (4) the among-countries variability in the monitoring and reporting effort.

Monitoring and reporting effort is a particularly important source of bias in any large-scale assessment of marine alien invasions. Syria, for example, is surrounded by countries with much higher reported numbers of marine aliens and within a region greatly affected by marine alien invasions (esp. Lessepsian species); thus, the relative low number of reported species in Syria (120) should be considered partly due to a low monitoring and reporting effort. Although the existence of national databases is not the only criterion to assess the reporting quality of countries, it has been found that it is linked to higher numbers of reported alien species (Gatto et al., unpublished data). It is noteworthy that none of the 13 countries with the lowest reported numbers of marine aliens (i.e. Georgia, Monaco, Montenegro, Bosnia and Herzegovina, Iceland, Albania, Slovenia, Bulgaria, Morocco, Ukraine, Algeria, Romania, and Portugal) has a national online database on marine alien species (see Table 1).

Apart from the lack of national databases, many other factors cause among-countries variability in the monitoring and reporting effort, such as differences in: national and regional policies and funding opportunities (e.g., to participate in important initiatives such as

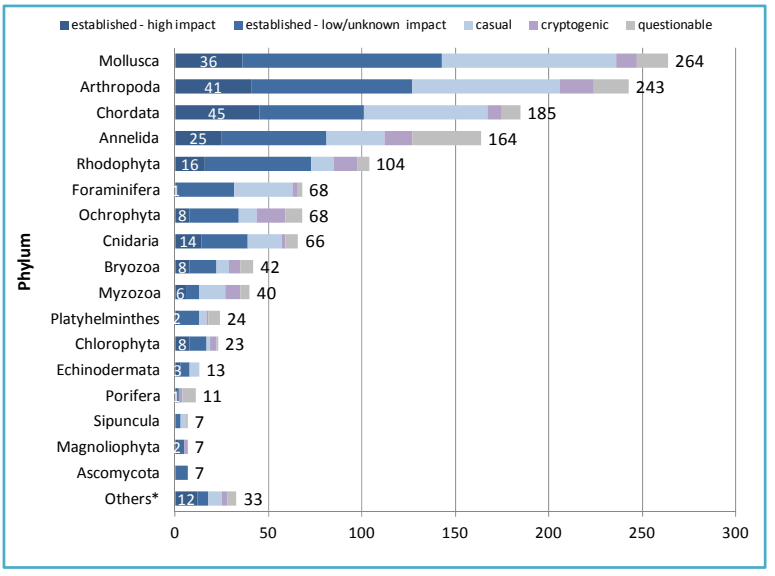

Figure 1. Reported marine alien species in Europe by phylum (version 2.1 of the EASIN catalogue; September 2012). The darker shading and white numbers correspond to the high impact species; black numbers aside the bars refer to the total reported number of alien/cryptogenic species of each phylum.

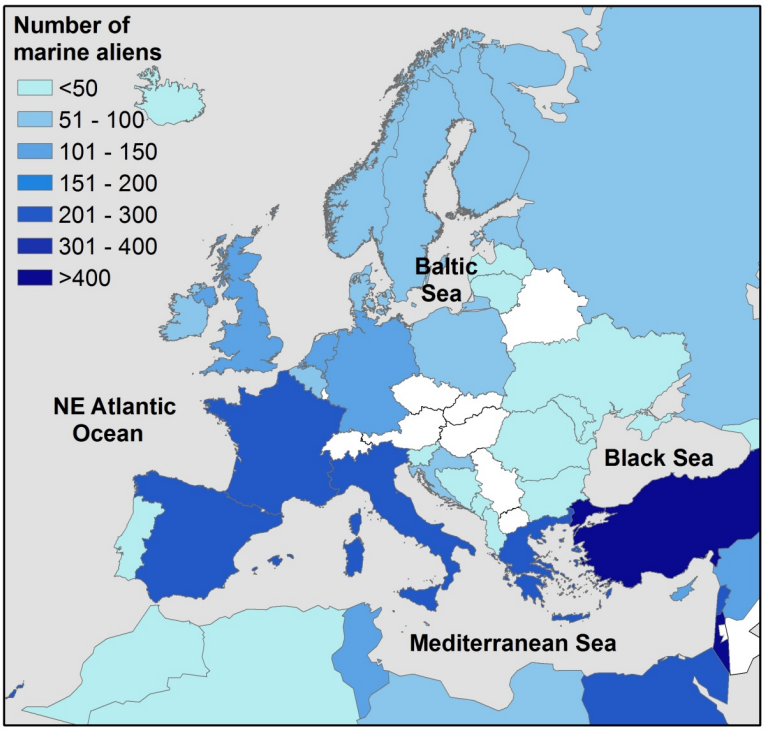

Figure 2. Number of reported marine alien species in European Seas by country. Landlocked countries appear in white.

DAISIE), availability of relevant expertise, and public awareness and participation in reporting networks. With greater monitoring and reporting effort, the number of reported species from many countries would probably increase substantially. Furthermore, there is still much information in the scientific and grey literature that has not been included in the existing online information systems, e.g. 149 marine ("coastal" or "brackish") alien species have been reported in Ukraine by Alexandrov et al. (2007), but five years after this publication, online databases only report 22 species.

There is still need for improvement in information on the spatial distribution of alien species within Europe. Most databases provided

species-presence information at country or sub-country (e.g. main islands) level. Only four databases provided geo-referenced records: BY-AQ (national of Belarus; only for aquatic species), FB (Fishbase; global but limited to fish), REABIC (Regional Euro-Asian), and UK (national for UK). When dealing with marine realm, country-level presence is insufficient and regional-sea-based information is more relevant, and needed. This is a major gap in knowledge, and future developments in information systems on alien species should focus on the provision of geo-referenced data or at least information by marine ecoregions or subregions. For the implementation of the EU Marine Strategy Framework Directive (EC 2008), information on marine alien species on a subregion basis is requested. Although there were some recent important efforts to assess marine biological invasions according to the MSFD approach (e.g. Zenetos et al. 2010), no online database has replaced the country-specific approach for reporting with the MSFD subregional approach.

Although there is a wealth of information on marine alien species distributions in Europe, there is a need for further harmonization of monitoring efforts and improvement of reporting, to effectively support relevant European policies and develop a better understanding of marine biological invasions.

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